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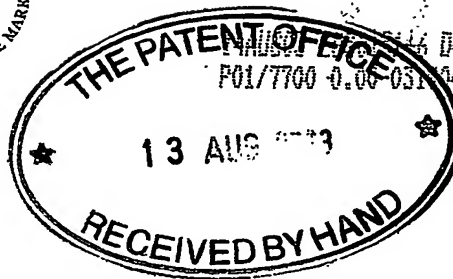
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Abstract

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23

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Osmotic Energy

The present invention relates to a process for driving a prime mover. The present invention also relates to an apparatus for generating energy.

When a dilute aqueous solution is separated from a concentrated aqueous solution by a semi-permeable membrane, water from the dilute aqueous solution will flow across the semi-permeable membrane to dilute the concentrated aqueous solution. The phenomenon is known as osmosis.

US 3,978,344 describes a process in which osmotic energy is converted into other forms of energy. Specifically, this reference describes a process in which a semi-permeable membrane is used to separate a body of freshwater from a body of seawater. The difference in osmotic pressure between the freshwater and the seawater causes water to pass through the membrane into the seawater, resulting in an increase in pressure on the seawater side of the membrane. The seawater may be ejected as a pressurised stream, which may be used to rotate a turbine.

The passage of freshwater through the semi-permeable membrane results in dilution of the seawater, which eventually limits the production of energy from a given body of seawater. Thus, the diluted seawater must be replenished periodically or continuously with fresh seawater.

According to the present invention, there is provided a process for driving a prime mover, said process comprising

a) positioning a semi-permeable membrane between a liquid and a solution having a higher solute concentration than the liquid, such that the solution becomes pressurised by the influx of liquid across the semi-permeable membrane,

5        b) using the pressure generated in the solution to drive a prime mover,

         c) recovering the solution,

         d) removing at least some of the solvent from the solution to produce a residual product, and

10       e) recycling the residual product to a solution for step a).

The prime mover of the present invention is preferably a rotary prime mover, for example, a turbine.

15       In the process of the present invention, a semi-permeable membrane is positioned between a liquid and a solution. The solution has a higher solute concentration (and, therefore, a lower solvent concentration) than the liquid. In other  
20       words, the total dissolved salt (TDS) concentration of the solution is higher than that of the liquid.

The difference in TDS between the liquid and the solution causes solvent to pass across the semi-permeable membrane  
25       from the side of low solute concentration (high solvent concentration) to the side of high solute concentration (low solvent concentration). This influx of liquid leads to an increase in pressure in the solution. For example, the pressure of the solution may be increased from a pressure in  
30       the range of  $10^5$  to  $10^7$  Pa to a pressure in the range of  $1.1 \times 10^5$  to  $5.0 \times 10^7$  Pa due to the influx of liquid. In a preferred embodiment, the pressure of the solution may be

increased from a pressure in the range of  $10^5$  to  $10^7$  Pa to a pressure in the range of  $1.5 \times 10^5$  to  $2.5 \times 10^7$  Pa due to the influx of liquid.

5 Step a) of the process of the present invention may be carried out in a housing. The housing is preferably provided with an inlet for introducing the liquid to one side of the semi-permeable membrane and an outlet for removing pressurised solution from the opposite side of the  
10 semi-permeable membrane. In a preferred embodiment, the influx of liquid into the solution is sufficient to eject the solution from the housing at a pressure of  $10^5$  to  $10^7$  Pa, preferably,  $1.1 \times 10^5$  to  $5.0 \times 10^7$  Pa and, more preferably,  $1.5 \times 10^5$  to  $2.5 \times 10^7$  Pa. The outlet of the housing may be  
15 sized to ensure that the solution is ejected at appropriate pressures. Additionally or alternatively, a nozzle may be coupled to the outlet to adjust the pressure of the solution accordingly.

20 The pressurised solution may be removed from the housing, for example, as a pressurised stream. The pressure generated in the solution is used to drive a prime mover. The solution may be introduced directly to the prime mover to drive the prime mover.

25 The pressure generated in the solution may be sufficient to eject the solution from the housing to an elevated height of, for example, 10 to 2500 m, preferably, 50 to 1500 m. Thus, the solution may be introduced to the prime mover from  
30 an elevated height. In this way, at least part of the potential energy of the solution is converted into mechanical energy. The mechanical energy of the prime mover

may be subsequently converted into other forms of energy, such as electricity and/or heat. In certain embodiments, it may be desirable to store the solution at an elevated location, prior to introducing the solution to the prime  
5 mover.

Once the pressure generated in the solution is used to drive the prime mover, the solution is recovered. Solvent is then removed from the solution. This solvent removal step may be  
10 carried out by any suitable method, for example, by evaporation, distillation, crystallization, ion-exchange, electrodialysis and/or osmosis (e.g. reverse osmosis or direct osmosis). Preferably, evaporation, distillation or crystallization is employed. A combination of one or more  
15 solvent removal techniques may be employed.

The thermal energy required to drive the solvent removal step may be provided by a number of sources. For example, the thermal energy may be provided by the surroundings (e.g.  
20 evaporation at ambient temperature), geothermal sources and/or solar energy. Evaporation at ambient temperature may be favoured in hot climates. It may also be possible to induce solvent removal by passing air, for example, warm air, over the solution, so as to effect evaporation of the  
25 solvent. Alternatively or additionally, the excess heat from a power station or an industrial process (e.g. a refinery or chemical plant) may be used to drive the solvent removal step. In other words, the solvent removal step of the present invention may be used to remove excess heat from an  
30 industrial process or power station.

In a further embodiment, the thermal energy required to drive the solvent removal step may be provided by the combustion of a fuel, such as oil, wood, peat, bushes, grass, straw, natural gas and coal. Waste products may also  
5 be incinerated to provide the thermal energy required for the solvent removal step.

In yet a further embodiment, the thermal energy required to drive the solvent removal step may be provided by biological  
10 processes, such as thermogenesis and fermentation.

The sources of thermal energy discussed above may be particularly useful for removing solvent by evaporation and/or distillation, for example, evaporation followed by  
15 distillation. A combination of one or more of these sources may be used.

Crystallization methods may be employed to separate solvent from the solution. To effect crystallization, the solution  
20 may be cooled to, for example, the freezing point of the solvent. This will cause some of the solvent in the solution to crystallize. This crystallized solvent may then be removed. Crystallization may be preferred in cool climates, where the low ambient temperatures may be used to  
25 reduce the temperature of the solution to effect crystallization.

Once solvent is removed from the solution, a residual product is produced. This residual product is recycled to a  
30 solution that is suitable for use in step a). For example, the residual product produced in step d) of the process may be recycled to the solution of step a) of that process.



Alternatively, when more than one of the processes of the present invention are carried out (e.g. concurrently), it is possible to recycle the residual product of one of the processes to step a) of another of the processes.

5

The process of the present invention may be carried out continuously, reducing or eliminating the need for replacing or replenishing the solution of step a) with fresh solution. It is also not necessary to add fresh solute to the solution, although this may be desirable in some instances.

10

The residual product may take the form of a solid product or a concentrated solution. Where the residual product is a solid product, the solid product may be added to the solution of step a) to increase the solute concentration of the solution of step a). This can help to maintain the difference in solute concentration between the two sides of the membrane, and ensure that the flow of liquid across the membrane occurs at a sufficient rate.

20

Where the residual product is a solid product, the solid product may also be diluted with solvent to produce a concentrated solution. This concentrated solution can be introduced to the solution of step a). By adjusting the concentration of this solution accordingly, the solute concentration of the solution of step a) may be maintained at desired levels. This can help to maintain the difference in solute concentration between the two sides of the membrane, and ensure that the flow of liquid across the membrane occurs at a sufficient rate.

25

30

When the residual product is a concentrated solution, the concentrated solution may be introduced to the solution side of the semi-permeable membrane of step a). In certain embodiments, it may be necessary to alter the concentration of the concentrated solution prior to use, for example, by adding more solvent or solute to the solution. By adjusting the concentration of the solution accordingly, the solute concentration of the solution may be maintained at desired levels. This can help to maintain the difference in solute concentration between the two sides of the membrane, and ensure that the flow of water across the membrane occurs at a sufficient rate.

The solvent removed in the solvent removal step may be recovered and recycled, for example, to a liquid that is suitable for use in step a). The solvent may be recycled as a vapour or a liquid and is preferably recycled as a liquid. The solvent removed in step d) of the process may be recycled to step a) of the process, or, alternatively, when a plurality of processes of the present invention are carried out (e.g. concurrently), the solvent removed in step d) of one particular process may be recycled to step a) of another process.

Alternatively or additionally, the removed solvent may be discarded or used for other purposes. In one embodiment, the liquid is seawater and the solution is an aqueous solution. Thus, the solvent removed from the solution in step d) is water. This water may be used for a number of applications, including agricultural, industrial and domestic applications (e.g. as drinking water). Thus, in

this embodiment of the present invention, the process of the present invention may be used to desalinate seawater.

When the removed solvent is recovered, it may be at an elevated temperature, particularly, if evaporation and/or distillation methods are used for solvent recovery. For example, the removed solvent may be at 30 to 500°C, preferably, 50 to 100°C. The thermal energy of the removed solvent may be used to heat the solution of step a).

10

It may be possible to replenish or to replace the liquid of step a) with fresh liquid, for example, periodically or continuously.

15 The liquid employed in step a) of the process of the present invention may or may not include a solute. The liquid is preferably water or an aqueous solution. For example, the liquid may be seawater, freshwater (e.g. from rivers, lakes and underground sources) and brackish water. Thus, the liquid may contain impurities that are typically found in water from these sources. For example, the liquid may contain dissolved salts, such as metal or ammonium salts. Examples of salts that may be present include fluorides, chlorides, bromides, iodides, sulphates, sulphites, sulphides, carbonates, hydrogencarbonates, nitrates, nitrites, nitrides, phosphates, aluminates, borates, bromates, carbides, chlorides, perchlorates, hypochlorates, chromates, fluorosilicates, fluorosilicates, fluorosulphates, silicates, cyanides and cyanates. Preferably, salts of alkali and/or alkali earth metals are employed. Examples of such metals include, but are not limited to, lithium, sodium, potassium, magnesium, calcium

20

25

30

and strontium. In one embodiment, the liquid is seawater and, therefore, includes sodium chloride in a concentration of at least 3 weight %.

- 5 In an alternative embodiment, the liquid may be an effluent from an industrial or agricultural process.

The solute concentration (i.e. TDS) of the liquid may be 0 to 10 weight %, preferably, 0.0 to 6 weight %.

10

- The solution is preferably an aqueous solution. Preferably, the solution is a solution of one or more inorganic salts. Suitable salts include metal or ammonium salts. Mixtures of two or more salts may be employed. Examples include, but  
15 are not limited to, fluorides, chlorides, bromides, iodides, sulphates, sulphites, sulphides, carbonates, hydrogencarbonates, nitrates, nitrites, nitrides, phosphates, aluminates, borates, bromates, carbides, chlorides, perchlorates, hypochlorates, chromates,  
20 fluorosilicates, fluorosilicates, fluorosulphates, silicates, cyanides and cyanates. Preferably, salts of alkali and/or alkali earth metals are employed. Examples of such metals include, but are not limited to, lithium, sodium, potassium, magnesium, calcium and strontium. In a  
25 preferred embodiment, the solution is an aqueous solution of sodium chloride.

Preferably, the solution is formed by introducing a known quantity of a solute into a known quantity of solvent.

- 30 Preferably, the solution consists essentially of a selected solute dissolved in a selected solvent. For example, in one embodiment, the solution is a salt solution having a salt

concentration of 2 to 400 weight %, preferably, 5 to 100 weight %, more preferably, 10 to 35 weight %, even more preferably, 15 to 20 weight %. In a preferred embodiment, the solution is a sodium chloride solution having a salt  
5 concentration of 2 to 39 weight %, preferably, 5 to 37 weight %, more preferably, 10 to 35 weight %, and even more preferably, 15 to 30 weight %.

The difference in TDS of the liquid and the solution may be  
10 at least 1 weight %, for example, from 1 to 39 weight %, preferably, 5 to 35 weight %.

Any suitable semi-permeable membrane may be used in the process of the present invention. An array of membranes may  
15 be employed. Suitable membranes include cellulose acetate (CA) and polyamide (PA) membranes. The membrane may be planar or take the form of a tube or a hollow fibre. Thin membranes may be employed. If desired, the membrane may be supported on a supporting structure, such as a mesh support.

20 In one embodiment, one or more tubular membranes may be disposed within a housing. The liquid may be introduced into the housing, whilst the solution may be introduced into the tubular membranes. As the solvent concentration of the  
25 liquid is higher than that of the solution, liquid will diffuse across the membrane into the solution. Thus, the solution will become increasingly diluted with liquid. The diluted solution may be recovered from the interior of the tubular membranes, whilst the liquid may be removed from the  
30 housing.

When a planar membrane is employed, the sheet may be rolled such that it defines a spiral in cross-section.

The pore size of the membrane may be selected depending on the size of the solvent molecules that require separation. It may be possible to use a membrane having a pore size that  
5 allows two or more different types of solvent molecules to pass through the membrane.

The flow of solvent across a semi-permeable membrane is generally influenced by thermal conditions. Thus, the  
10 liquid and solution on respective sides of the semi-permeable membrane may be heated or cooled, if desired. Preferably, the solution is heated to a temperature of 30 to 90°C, preferably, 50 to 70°C. The liquid may be cooled, for example, to 5 to 20°C, for example, 7 to 12°C. Chemical  
15 reactions may also be carried out on either side of the membrane, if desired. In one embodiment, the solution and/or liquid may be agitated.

The process of the present invention may further comprise a  
20 pre-treatment step of removing contaminants, such as suspended particles and biological matter, from the liquid (e.g. a waste stream, seawater, river water, lake water or brackish water). Additionally or alternatively, a threshold inhibitor to control scaling may be added to the liquid.  
25 Pre-treatment steps to alter the pH of the liquid may also be employed.

According to a further aspect of the present invention, there is provided an apparatus for generating energy, said  
30 apparatus comprising  
a prime mover,

a housing comprising a semi-permeable membrane for separating a liquid from a solution having a higher solute concentration than the liquid and configured such that liquid passing through the membrane pressurises the solution,

means for transmitting the pressure generated in the solution to the prime mover,

means for recovering the solution,

means for removing solvent from the solution to produce a residual product, and

means for recycling the residual product to a solution for the housing.

The residual product may be recycled to solution contained in the housing of the apparatus. Alternatively, the residual product may be recycled to solution contained in the housing of another apparatus according to the present invention.

The prime mover may be a rotary prime mover, such as a turbine.

These and other aspects of the present invention will now be described with reference to the accompanying drawings, in which

Figure 1 is a schematic flow diagram of a process according to a first embodiment of the present invention,

Figure 2 is a schematic flow diagram of a process according to a second embodiment of the present invention, and

Figure 3 is a schematic flow diagram of a process according to a third embodiment of the present invention.

Reference is first made to Figure 1 of the drawings. This Figure depicts a process according to a first embodiment of the present invention. The process is performed using an apparatus 10 comprising an osmotic cell 12, a prime mover 14 (e.g. turbine) and a separator 16. The osmotic cell 12 comprises a semi-permeable membrane 18.

In use, water (e.g. seawater) is introduced to one side of the membrane 18. A 30 weight % solution of sodium chloride is introduced to the opposite side of the membrane 18. As the sodium chloride solution has a sodium chloride concentration that is higher than the total dissolved salt (TDS) concentration of seawater, water flows across the membrane 18 by osmosis. The influx of water across the membrane 18 increases the pressure of the sodium chloride solution.

The pressurised sodium chloride solution is removed from the osmotic cell 12 and introduced to the prime mover 14. It is not necessary to pump the sodium chloride solution as the solution is pressurised by the osmosis step. The pressurised sodium chloride solution is used to drive the prime mover 14. The mechanical energy produced may be converted to other forms of energy, such as electrical energy.

The sodium chloride solution may then be removed from the prime mover 14 and introduced into the separator 16. In the separator 16, water is removed from the sodium chloride



solution by evaporation. Once water is removed from the sodium chloride solution, the sodium chloride solution is recycled to the osmotic cell 12 for re-use. Thus, fresh sodium chloride solution is not required to replenish or  
5 replace the sodium chloride solution in the osmosis step.

The water removed in the evaporation step may be recovered and used, for example, as drinking water. Thus, this embodiment of the present invention may be used to  
10 desalinate seawater. The water removed in the evaporation step may alternatively be recycled to the water side of the membrane 18 of the osmotic cell 12. As a further alternative, the water may be used to heat the sodium chloride in the osmotic cell 12.

15 The apparatus 10 is located in close proximity to a conventional power station 22. The power station 22 comprises a boiler 24, a prime mover 26 (e.g. steam turbine) and a thermal unit 28 (e.g. condenser in power station 22).

20 In use, water is introduced into the boiler 24 via a pump 30. The water is heated in the boiler 24 by the combustion of fuel 32 to produce superheated steam. The superheated steam is then introduced at high pressure to the prime mover  
25 26, and is used to drive the prime mover 26 to generate mechanical energy. The mechanical energy of the rotating prime mover 26 may be converted into other forms of energy, such as electrical energy.

30 Saturated or superheated steam is then recovered from the prime mover 26 and introduced into the thermal unit 28. In the thermal unit, the steam is condensed to water. The

excess heat from the steam is used to evaporate water from the solution of apparatus 10. Thus, the sodium chloride solution from the prime mover 14 of apparatus 10 is used as a coolant in the thermal unit 28 of the power station 22.

5 The separator 16 of apparatus 10, therefore, is effectively the same as the thermal unit 28 of the power station 22.

The condensed steam of the power station 22 is recycled to the boiler 24 via the pump 30.

10

Reference is now made to Figure 2 of the drawings. This figure depicts a process according to a second embodiment of the present invention. The process is performed using an apparatus 100. Apparatus 100 is similar to the apparatus 10  
15 of Figure 1 and like components of the apparatus have been labelled with like numerals. Apparatus 100, however, is adapted for use in cold climates. Thus, unlike the apparatus 10 of Figure 1, the apparatus 100 comprises a separator 116 that is a crystallizer. In use, solution  
20 emerging from the prime mover 14 is introduced into the separator 116 and cooled by the ambient temperature to produce ice and a concentrated sodium chloride solution. The former is removed and discarded, whilst the latter is recycled to the osmotic cell 12.

25

Reference is now made to Figure 3 of the drawings. This figure depicts a process according to a third embodiment of the present invention. The process is performed using an apparatus 200. Apparatus 200 is similar to the apparatus 10  
30 of Figure 1 and like components of the apparatus have been labelled with like numerals. Apparatus 200, however, is adapted for use in warm, dry climates. Thus, unlike the

apparatus 10 of Figure 1, the apparatus 100 comprises a separator 216 that relies on natural or effective evaporation and/or solar energy to remove solvent from the solution emerging from the prime mover 14.

Claims

1. A process for driving a prime mover, said process  
5 comprising
  - a) positioning a semi-permeable membrane between a liquid and a solution having a higher solute concentration than the liquid, such that the solution becomes pressurised by the influx of liquid across the semi-permeable membrane,  
10
  - b) using the pressure generated in the solution to drive a prime mover, and
  - c) recovering the solution,
  - d) removing at least some of the solvent from the solution to produce a residual product, and  
15
  - e) recycling the residual product to a solution for step a).
2. A process as claimed in claim 1, wherein the prime  
20 mover is a rotary prime mover.
3. A process as claimed in claim 1 or 2, wherein the solution is an aqueous solution.
4. A process as claimed in any one of the preceding  
25 claims, wherein the solution is a sodium chloride solution.
5. A process as claimed in claim 4, wherein the solution is a 2 to 39 weight % sodium chloride solution.
- 30 6. A process as claimed in any one of the preceding claims, wherein the liquid is selected from the group

consisting of freshwater, seawater, brackish water and a waste stream from an industrial or agricultural process.

7. A process as claimed in any one of the preceding  
5 claims, wherein solvent is removed in step d) by a method selected from the group consisting of evaporation, crystallization, ion-exchange, electrodialysis and osmosis.

8. A process as claimed in any one of the preceding  
10 claims, wherein the energy required to remove solvent in step d) is provided by the thermal energy of the surrounding environment, solar energy, geothermal energy, energy from a biological process, energy from the combustion of fuel and/or excess heat from a power station or an industrial  
15 process.

9. A process as claimed in any one of the preceding claims, wherein at least some of the solvent recovered in step d) is recycled to a liquid for step a).

20

10. An apparatus for generating energy, said apparatus comprising

a prime mover,

a housing comprising a semi-permeable membrane for  
25 separating a liquid from a solution having a higher solute concentration than the liquid and configured such that liquid passing through the membrane pressurises the solution,

means for transmitting the pressure generated in the  
30 solution to the prime mover,

means for recovering the solution,

means for removing solvent from the solution to produce a residual product, and

means for recycling the residual product to a solution for the housing.

5

11. An apparatus as claimed in claim 10, wherein the prime mover is a rotary primary mover.

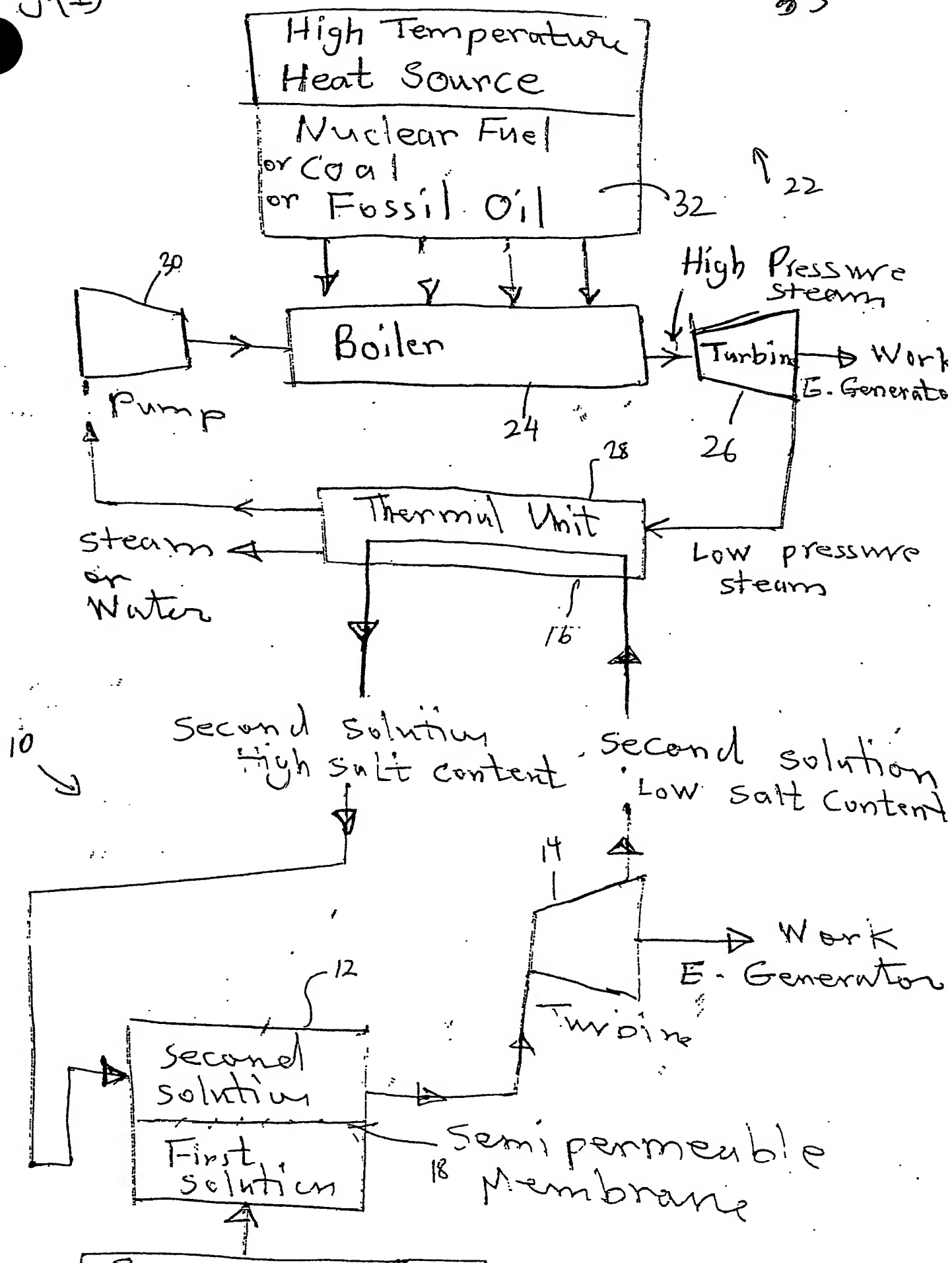
12. An apparatus as claimed in claim 11, wherein the rotary  
10 prime mover is a turbine.

13. A process as described herein with reference to the accompanying drawings.

15 14. An apparatus as described herein with reference to the accompanying drawings.

Fig. (1)

21  
83



Fig(2)

# Cold Climate

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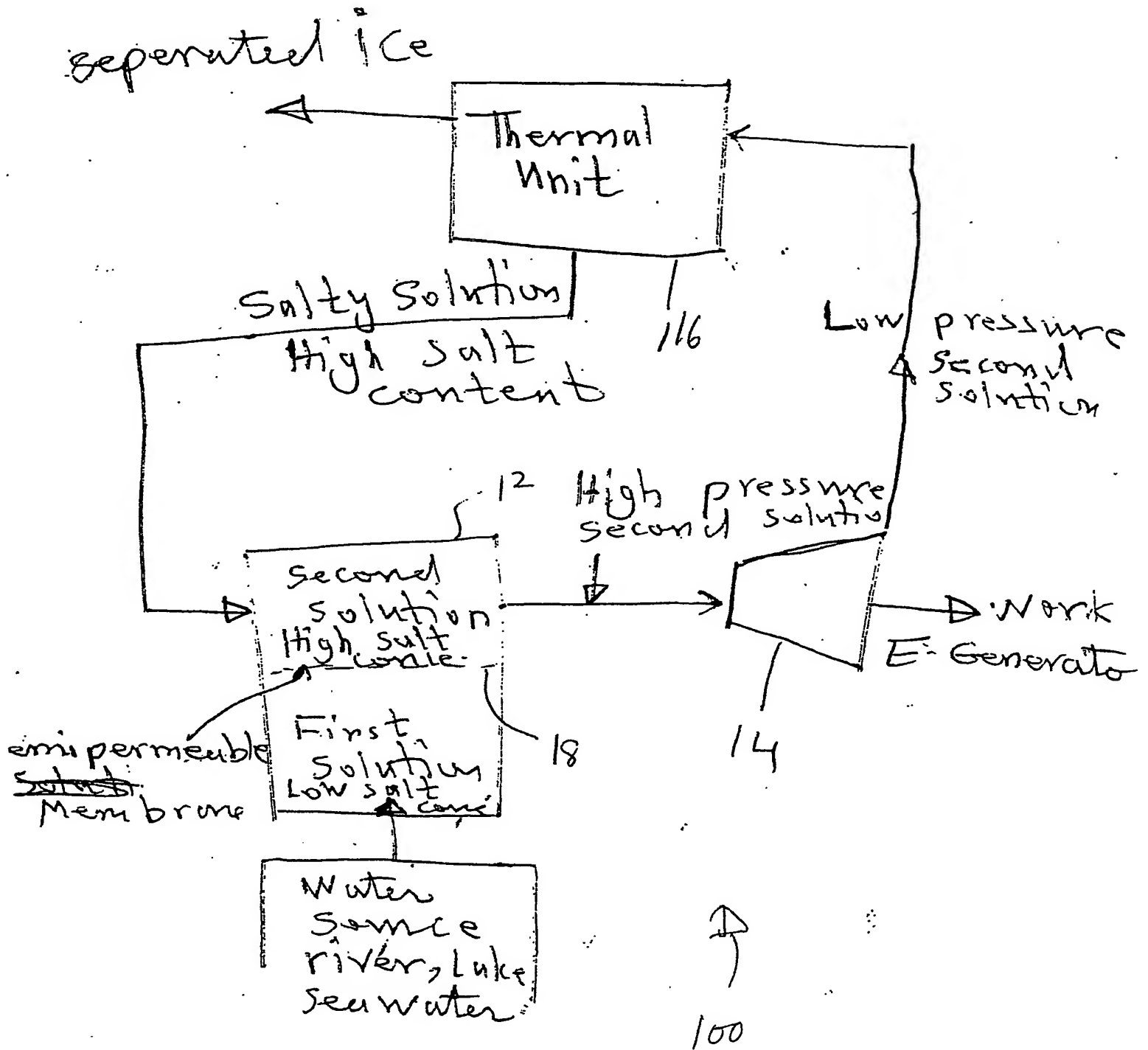
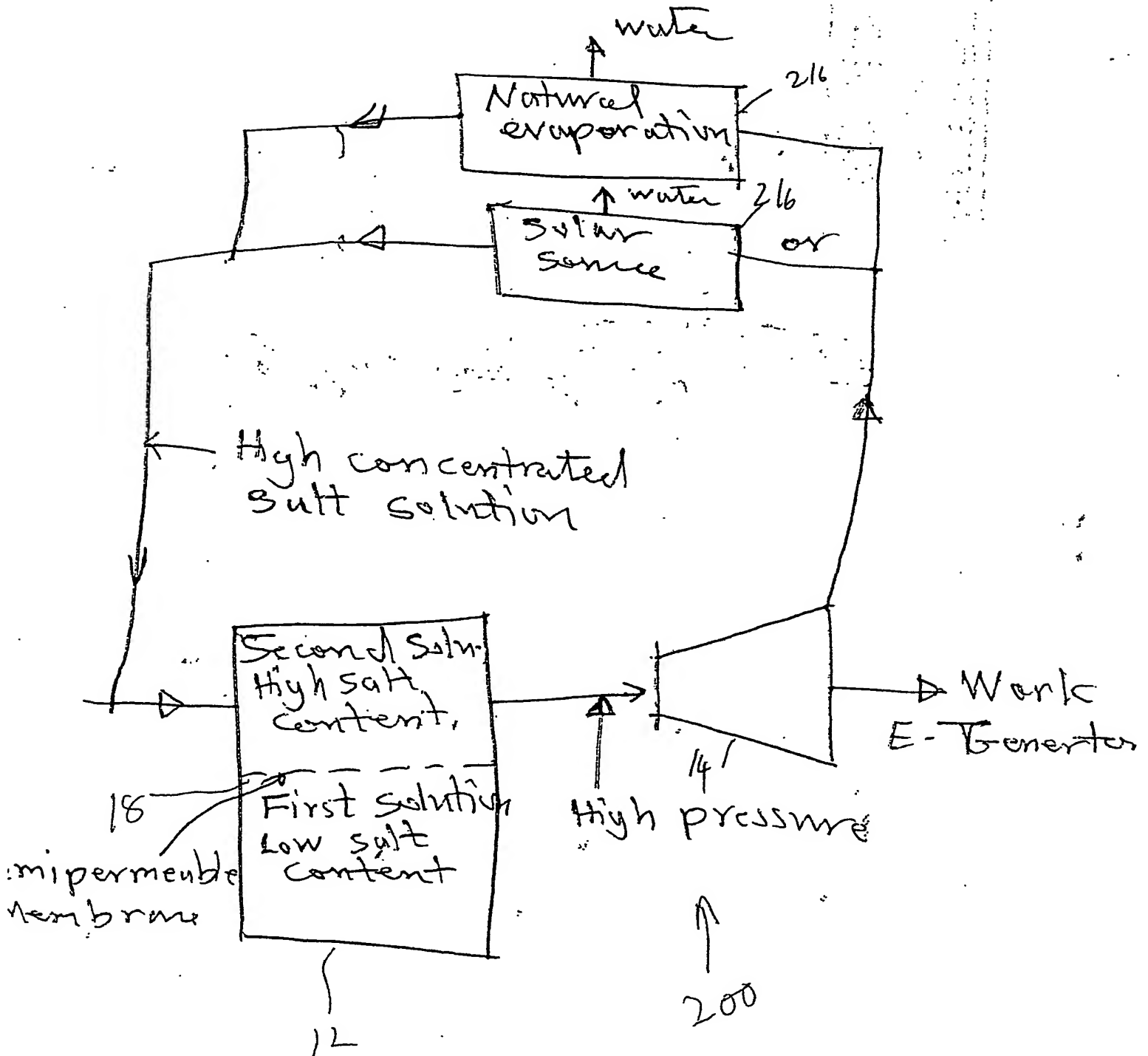


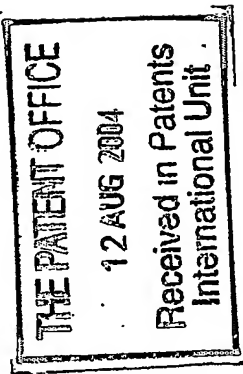


Fig. (3)

# Hot Climate

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